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Published in:
World neurosurgery

DOI:
10.1016/j.wneu.2018.07.219

Three-Dimensional Planning and Use of Individualized Osteotomy-Guiding Templates for Surgical Correction of Kyphoscoliosis: A Technical Case Report

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■ OBJECTIVE: **We have described the use of 3-dimensional (3D) virtual planning and 3D printed patient-specific osteotomy templates in the surgical correction of a complex spinal deformity. Pedicle subtraction osteotomies (PSOs) for the correction of severe spinal deformities are technically demanding procedures with a risk of major complications. In particular, operations of the severely deformed spine call for new, more precise, methods of surgical planning. The new 3D technology could result in new possibilities for the surgical planning of spinal deformities.**

■ METHODS: **We present the case of severe congenital kyphoscoliosis in a young girl with skeletal dysplasia. A closing wedge-extended PSO was 3D virtual planned using medical computer design software. After the optimal 3D-wedge procedure was planned, individualized osteotomy-guiding templates were designed for translation of the planned PSO to the surgical procedure. During surgery, the PSO was performed using the osteotomy templates. Successful correction of the kyphoscoliosis was realized.**

■ RESULTS: **The kyphosis was successfully reduced using a wedge-shaped extended PSO using preoperative 3D virtual planning, assisted by 3D-printed individualized osteotomy-guiding templates.**

■ CONCLUSIONS: **In addition to direct translation of the planned PSO for surgery, the 3D planning also facilitated a detailed preoperative evaluation, greater insight into the case-specific anatomy, and accurate planning of the required correction.**

INTRODUCTION

Vertebral column resection and pedicle subtraction osteotomy (PSO) with posterior fixation are widely indicated for patients with rigid, sharp, angular thoracic kyphosis, such as kyphosis >70° in the sagittal plane, congenital kyphosis, and hemivertebrae.[1-3] To reduce the risk of injuries during the osteotomy and pedicle screw insertion, computer-assisted surgery systems have been commonly used. In the case of closing-wedge vertebral osteotomy, the global osteotomy planes can be roughly planned using the available preoperative imaging data. However, the procedure remains technically demanding with a risk of major complications.

The development of 3-dimensional (3D) surgical planning and printing has evolved rapidly within various surgical specialties. This technology could result in new possibilities for the surgical planning of spinal deformities. In this report, we present a new approach for complex closing wedge procedures by describing the case of a young girl with severe angular thoracolumbar kyphoscoliosis. We developed a workflow for precise 3D surgical planning for spinal deformities. The method includes the production and application of osteotomy templates for translation of the planned wedge to the surgical procedure. To the best of our knowledge, the presented strategy for 3D spinal osteotomy planning has not been previously reported.

Key words
- 3D planning
- 3D printing
- 3D surgery
- Kyphosis
- Scoliosis
- Spinal deformity
- Templates

Abbreviations and Acronyms
3D: 3-Dimensional
CT: Computed tomography
PSO: Pedicle subtraction osteotomy

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Supplementary digital content available online.

Citation: World Neurosurg. (2018) 119:113-117.
https://doi.org/10.1016/j.wneu.2018.07.219

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

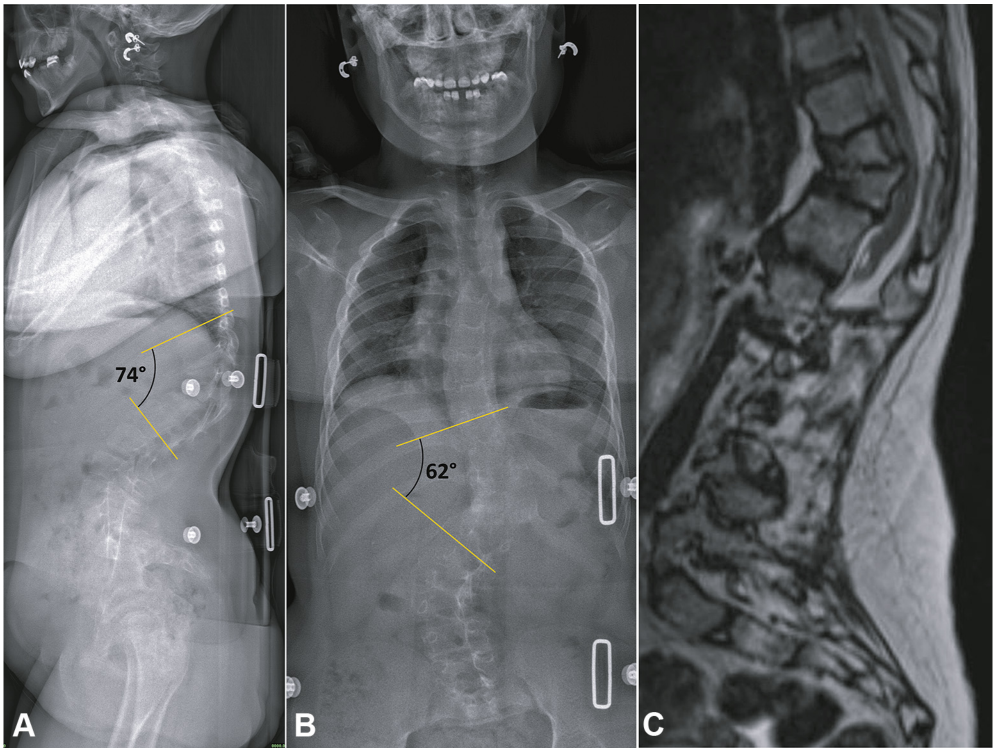

Figure 1. Preoperative imaging data showing (**A**) standing lateral radiograph film with the patient wearing her brace. (**B**) Standing posteroanterior radiograph film with the patient wearing her brace. (**C**) Magnetic resonance imaging scan showing the kyphotic deformity with elongation of the spinal cord.

CASE DESCRIPTION

A 12-year-old girl presented with skeletal dysplasia and severe congenital kyphoscoliosis. On physical examination, no sensory or motor loss was found. Radiographic film measurements revealed a kyphosis angle of 74° in the sagittal plane and scoliosis with a Cobb angle of 62° (**Figure 1A, B**). Preoperative computed tomography (CT) imaging showed trapezoidal anterior wedging of the T12 and L1 vertebrae. Moreover, a butterfly-shaped T11 vertebra with minimal fusion of the 2 body centers was found. Magnetic resonance imaging studies revealed anterior positioning and stretching of the spinal cord over the kyphotic deformity, without signs of myelopathy (**Figure 1C**). Initially, she was treated with a brace; however, because of the progressive and rigid deformity, it was decided to perform an extended PSO with posterior fixation to prevent any further progression and future neurological deficits.

The aim was to perform a closing wedge bone—disc—bone resection between T11 and T12, with the hinge located at the anterior longitudinal ligament. This osteotomy can be classified as grade 4P according to the Schwab classification system.[4] We aimed for a correction of approximately 40° to prevent excess dural buckling during wedge closure. Given the complexity of the present case and the importance of flat osteotomy surfaces for bony fusion, a multidisciplinary team was established to explore the assistance of 3D surgical planning. The team of surgeons and technical physicians, with 3D planning experience in our hospital, developed a 3D-guided method for closing wedge osteotomies for complex spinal deformities.

METHODS

Using Mimics, version 19 (Materialise, Leuven, Belgium), a 3D spine model was reconstructed using threshold-based bone segmentation of the acquired CT data (slice thickness, 0.6 mm). The models were exported to stereolithographic files, and further 3D planning and modeling was performed using 3-matic, version 11 (Materialise). The aim was to correct the severe kyphoscoliosis by the closure of a 3D-shaped wedge that hinged on the anterior column. Virtual 2-step plane and cut positioning was repeated until the optimal 3D wedge was reached. Care was taken to plan for sufficient bony contact surfaces for optimal wedge closing. The final wedge included a bone—disc—bone osteotomy with the apex located between T11 and T12 (**Figure 2A, B**). The superior margins of the wedge included the intervertebral disc, its cartilage endplates, and the subchondral bone caudally of the pedicles. The wedge inferior margins were planned to be just beneath the pedicles of T12, thereby creating large foramina to accommodate both nerve roots.

The 3D wedge planning strategy we have presented requires a method that enables translation of the planned PSO to the

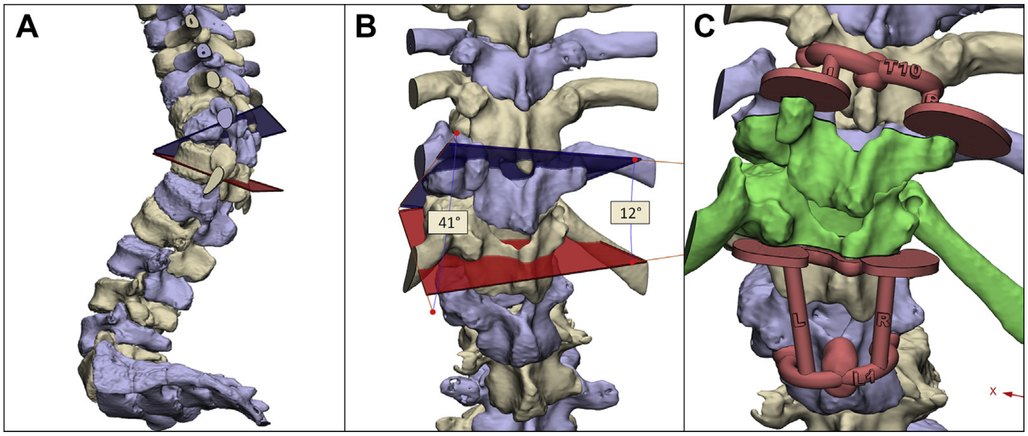

Figure 2. (**A**) Lateral view of the preplanned 3-dimensionally shaped wedge, superimposed on the 3-dimensional model of the spine. The cranial osteotomy plane (*blue*) is positioned through the butterfly-shaped T11 vertebra. The caudal osteotomy plane (*red*) was planned just below the pedicles of T12, allowing for transposition of the 11th nerve root. (**B**) Posterior view of the planned angular reduction, kyphosis reduction of 41°, and a scoliosis reduction of 12°. (**C**) Posterior view showing templates positioned on the vertebrae, in line with the planned osteotomy planes. The planned pedicle subtraction osteotomy is indicated in *green*.

surgical procedure. We, therefore, chose to design individualized osteotomy-guiding templates cranially and caudally from the planned wedge (**Figure 2C**). **Supplemental Video 1** shows an animation of the 3D planned correction and the use of the osteotomy-guiding templates. The osteotomy planes were transformed into solid, oval-shaped planes that fit to the bone and could guide the surgical chisel. In addition, laminae and spinous process contact areas were created on adjacent vertebrae, because, during the procedure, we might lose the initial contact areas at the level of the laminectomy (T11 and T12). Subsequently, the additional contact areas were connected to the oval templates by cylindrical shapes. Essential for the use of this multilevel guide concept is the presence of a severe rigid spine complex, which was confirmed by lateral bending radiographs, to ensure that the vertebral positions in the virtual planning environment are maintained during surgery. The final osteotomy

Video

Video available at WORLDNEUROSURGERY.org

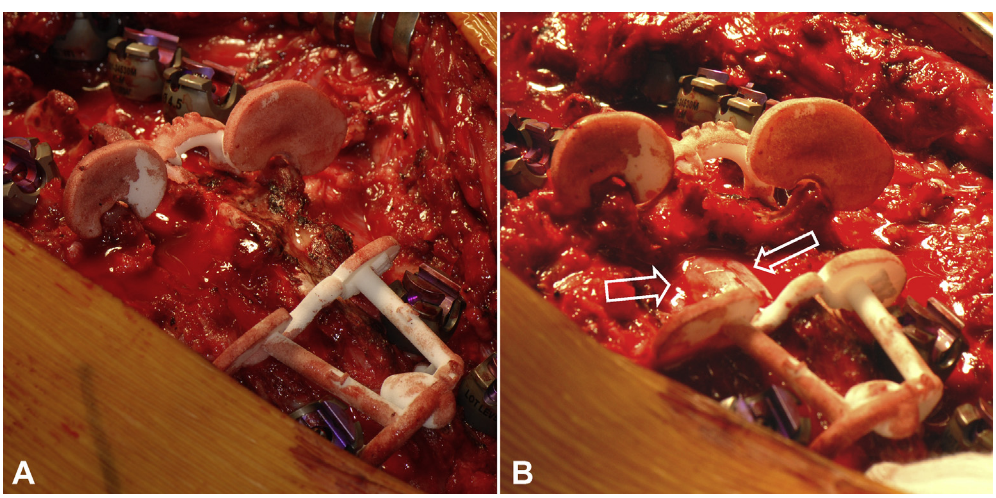

Figure 3. (**A**) Intraoperative placement of the osteotomy-guiding templates on the vertebrae. (**B**) Wedge-shaped extended pedicle subtraction osteotomy was performed along the planes of the templates. Note the central located dural sac (*white arrows*).

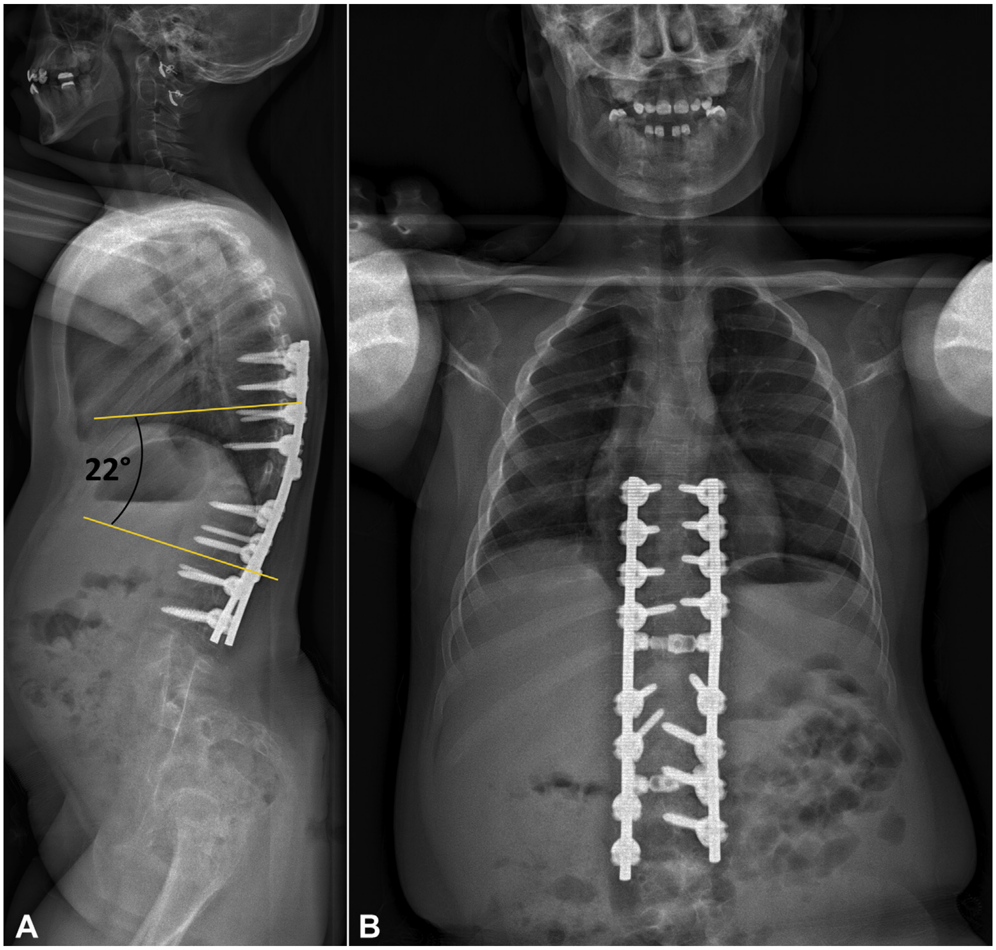

Figure 4. Postoperative radiograph showing good correction of the deformity. (**A**) Lateral film showing an angular kyphosis reduction from 74° to 22°. (**B**) Posteroanterior film.

templates and bone models were printed using a 3D printer in polyamide and sterilized using autoclave steam sterilization.

During surgery, the 3D-printed bone model facilitated visual intraoperative guidance and identification of the vertebral levels. Pedicle screws were inserted using computer-assisted surgery at 4 levels on either side of the desired vertebral resection. Next, soft tissue was carefully removed from the spinous processes and laminae to ensure a tight bone contact and optimal fit of the osteotomy templates. A good fit of the templates on the vertebra was realized, confirming that the individual vertebral positions were correct and no segmental shift had occurred after the preoperative CT scan (**Figure 3A**). The first part of the osteotomy into the vertebral body was performed using a surgical chisel (**Figure 3B**). After creating the initial cuts, the templates were removed, and stabilization rods were inserted. The PSO was further completed by piecemeal resection along the initial plane created using the templates. Subsequently, compressive forces were applied to close the wedge. This forced the 2 nerve roots into the single, large, newly created foramen.

The postoperative period was uneventful, and she was discharged without any neurological deficit after 8 days. The early postoperative radiographs showed satisfactory correction of the kyphoscoliosis, the kyphosis angle was reduced from 74° to 22°, and her coronal plane was normalized (**Figure 4**).

DISCUSSION

The case we have presented describes the value of 3D virtual planning and translation toward the surgical procedure using printed models (3D spine bone model and osteotomy templates) during kyphoscoliosis-correcting surgery. The 3D planning and templates facilitated surgery in 4 key ways: 1) 3D insight of the case-specific anatomy; 2) identification of vertebral levels during surgery; 3) visualization of the malformed vertebrae and their relation to the spinal cord; and, most importantly, 4) direct translation of the planned PSO into the surgical site using 3D printed individualized osteotomy-guiding templates.

The use of 3D virtual surgical planning and individualized osteotomy templates is a mature and widely accepted technique in oral and maxillofacial surgery.[5-7] In spine surgery, the usefulness of 3D printed anatomical models has been previously reported.[8] Recent research in individualized templating for spine surgery, which translates the 3D virtual plan to surgery, has been limited to drill guides for accurate pedicle screw placement.[9-12] Patient-specific osteotomy templates have often been described for knee arthroplasty[13,14]; however, to the best of our knowledge, ours is the first report describing this technique for complex spinal osteotomies. We have demonstrated in the present case that this 3D planning and printing technique is feasible for surgery of complex spinal deformities. From the surgeon's perspective, the templates and bone models provided valuable guidance during the osteotomy in the severely deformed anatomy. Moreover, the surgeons reported that studying the 3D anatomy in a multidisciplinary team facilitated the surgical procedure owing to the enhanced spatial orientation.

The templates were designed to fit specific vertebrae, guiding the surgeon in performing the PSO according to plan. To maintain a good fit after laminectomy, the templates were designed as a multilevel osteotomy guide. The templates and bone models (T10—L2) were produced in polyamide using selective laser sintering printing, with a production cost of U.S. $175 for the present case. Although the production costs were relatively low, most of the costs of these 3D planning procedures can be attributed to the time investment of the design specialists. The presented case required a full day of work for segmentation and template design. The presented method could, in the future, be cost-effective because it might reduce the operative time and preclude the need for intraoperative radiography, especially when combined with patient-specific drill guides.

Although the templates provided great directional support for the surgeon, the use was nevertheless limited to the first stages of the PSO. When approaching the apex of the wedge, temporary rods had to be placed for stabilization and safety. These rods could not be placed simultaneously with the templates. The future design of templates can, therefore, be optimized and incorporate inlets for rod positioning. Also, the use of Kirschner wires for temporary template fixation can be of benefit to maintain the position after partial bone resection, especially when performing grade 3 PSO (Schwab classification system), using single-level template support. The present feasibility study was limited to describing the technical aspects and the use of this new method in a qualitative manner. For future studies, the technique should, therefore, be subjected to a comprehensive accuracy study, relating the findings to the clinical outcomes and, thereby assessing its efficacy in a quantitative manner.

CONCLUSIONS

The novel use of 3D virtual planning, 3D-printed spine models, and osteotomy-guiding templates have facilitated the performance of the osteotomy and could, in the future, contribute to safer spinal osteotomy procedures.

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Received 1 March 2018; accepted 24 July 2018

Citation: World Neurosurg. (2018) 119:113-117.
https://doi.org/10.1016/j.wneu.2018.07.219

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